DEVELOPING BODY GESTURE INTERACTION GUIDELINES WITH PASSENGER ELICITATION FOR ADJUSTING HIGHLY AUTOMATED VEHICLE DYNAMICS

A Thesis
Presented to
The Academic Faculty

by

Hongnan Lin

In Partial Fulfillment
of the Requirements for the Degree
Master of Industrial Design in the
SCHOOL OF INDUSTRIAL DESIGN/COLLEGE OF DESIGN

Georgia Institute of Technology
August 2019

DEVELOPING BODY GESTURE INTERACTION GUIDELINES WITH PASSENGER ELICITATION FOR ADJUSTING HIGHLY AUTOMATED VEHICLE DYNAMICS

Approved by:

Dr. Wei Wang, Advisor
School of Industrial Design
Georgia Institute of Technology

Prof. Jim Budd
School of Industrial Design
Georgia Institute of Technology

Dr. Young Mi Choi
School of Industrial Design
Georgia Institute of Technology

Date Approved: 5/10/2019

ACKNOWLEDGMENTS

First and foremost, I would like to thank my advisor, Dr. Wei Wang, for his continuous support and guidance. I am always inspired by his patience, motivation, and enthusiasm. His feedback was straightforward and honest at times, not just for this thesis but for preparing me for my future academic career.

I also would like to thank the rest of my committee members, Prof. Jim Budd and Dr. Young Mi Choi, for their challenge, encouragement, and insightful comments.

I want to thank my parents and sister for checking up on me constantly and making sure I was well, my roommates for their concern and help in my daily study life.

Last but not least, I would like to thank my awesome partner, Zechen, who always believes in me, inspires me, and comforts me through challenging times.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

ADB	Autonomous driving behavior
HMI	Human-machine interaction
HAV	Highly automated vehicle
VR	Virtual Reality
HMD	Head-mounted display

SUMMARY

Highly Automated Vehicles (HAVs) could provide better safety, convenience, and eco-friendliness. However, realizing those benefits depends on not only the technical breakthrough but also the extent of people's usage, which is significantly influenced by whether HAV driving styles match passengers' preference. Therefore, this research studies user-elicited whole-body gestures for communicating the intention of adjusting vehicle dynamics in HAVs to provide design implications for the corresponding human-machine interaction (HMI).

The study was based on user-elicitation gesture design method that immersed participants in HAV riding scenarios with a virtual reality (VR) simulator and elicited their gesture design for adjusting vehicle dynamics in HAV. The HAV driving scenarios, stemming from the literature on future HAV use cases and HAV ride plots, consist of three different road profiles and 15 discomfort-inducing plots. Participants were required to perform gesture interaction when they felt unsatisfied with the vehicle dynamics while experiencing the scenarios, report their interaction intentions and rationale of their gesture design after experiencing the scenarios, and draw down their interface need if there was.

The user test (*N*=12) produced five kinds of intentions, at least one gesture design accompanied by explanations for each intention from each participant, and 12 sets of HMI design sketches. Based on the analysis of collected data, a taxonomy of whole-body gesture interaction for adjusting HAV dynamics was proposed. It was demonstrated that consensus existed among the participants on the gesture design. According to the consensus extent, an end-user generated gesture set was constructed. This paper highlights the implications of this work to the design of

HAV HMI that assists passengers with communicating their intention of adjusting vehicle dynamics.

CHAPTER 1. INTRODUCTION

1.1 Background

The continuing evolution of automotive technology aims to deliver autonomous driving systems that can handle all the driving task when occupants do not want to or cannot do it along with advantages such as reducing traffic accidents, congestion, and energy consumption. Highly Automated Vehicles (HAVs), which have Level 3 or above driving automation, require no manual driving when automated driving features are engaged (SAE International, 2015), see Figure 1. They are integrating onto roadways by progressing through different use cases in the coming years including the interstate pilot, autonomous valet parking, fully autonomous driving in permitted areas, and fully autonomous on-demand vehicles (Wachenfeld et al., 2016). However, in addition to technical aspects, realizing the expected benefits of HAV also depends on the extent of usage, which greatly depends on whether the HAV driving style matches occupants' preference (Jamson, 2006; Siebert, Oehl, Höger, & Pfister, 2013; Elbanhawi, Simic, & Jazar, 2015).

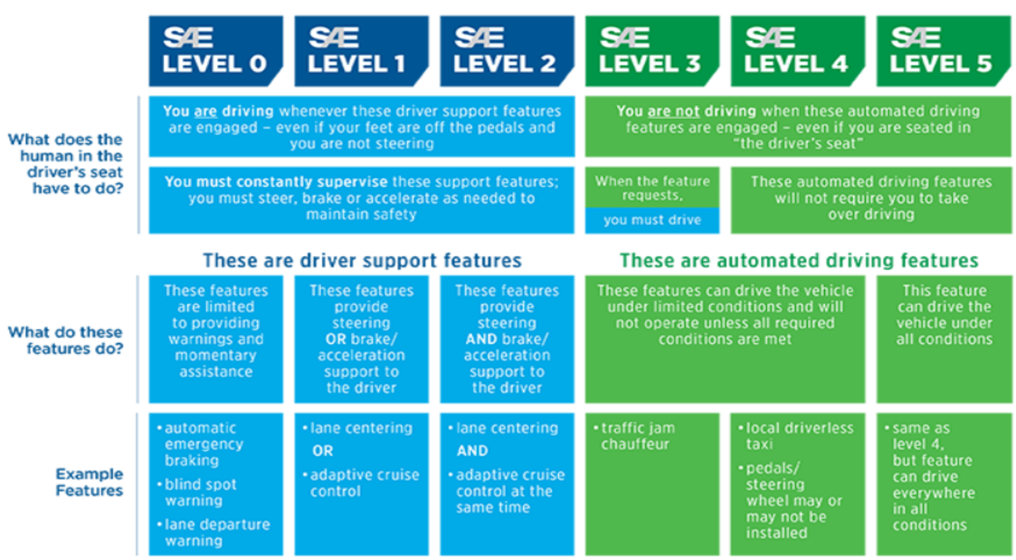


Figure 1 SAE J3026^{TM} Levels of Driving Automation (SAE International, 2015).

Whereas HAVs operates based on optimized logic maximizing safety (SAE International, 2015), human drivers' driving styles depend on their emotions (Li, Li, Rajamani, & Wang, 2011) and motivations (Fagnant & Kockelman, 2014). Hence, conflicts may arise between HAV driving styles and occupants' preference. There are tons of factors associated with occupants' preference of driving styles such as the road profile, the leading vehicle, the secondary task of occupants, and so on. Therefore, much research needs to be done to match HAV driving styles to occupants' preference.

The terms of Driving Behavior, Driving Style, Vehicle Dynamics often appear in related articles. For this article's clarity, the differences between them are distinguished as: ***Driving Behavior*** is operation or manipulation including the pattern of acceleration, braking, turning, the harshness and frequency (Miyajima et al., 2007). ***Driving Style*** is human emotional perceptions of driving behaviors, it can be described as risky or careful, assertive or defensive (Taubman-ben-ari, Mikulincer, & Gillath, 2004). ***Vehicle dynamics*** is a consequent motion manifestation of driving behavior, commonly including the velocity and accelerations in three directions (longitudinal, lateral, and vertical directions) (Elbanhawi et al., 2015).

To identify satisfying HAV driving style, Bellem et al. (2016) identify a variety of maneuver-specific metrics, such as acceleration, jerk, quickness and headway distance in seconds, were identified, which can be used to parameterize an everyday, a comfort, or a dynamic driving style. Karjanto et al. (2017) investigate participants' preferences of acceleration forces and driving styles (defensive, assertive and light rail transit) on different road profiles and the correlation between participants' preference and their own driving style

While this study aims at assisting occupants with communicating their intention of adjusting the ongoing vehicle dynamics so that HAVs can modify its driving style accordingly to maintain occupants' satisfaction (shown in Figure 2). Specifically, this research studies user-elicited gesture design to provide design implications for HAV Human-Machine Interaction (HMI) that assists passengers with communicating their intention of adjusting vehicle dynamics simultaneously and straightforwardly. This study has a vision of a future city where HAVs are fully deployed in that the potential users of the interfaces may have different levels of situation awareness and driving skills from today's drivers.

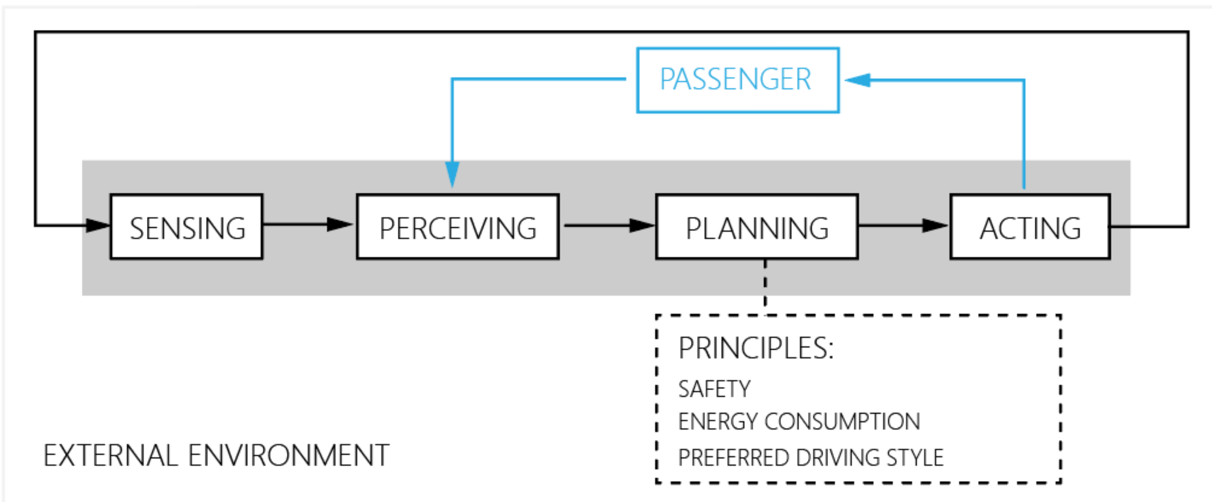


Figure 2 Proposed interaction in the HAV workflow.

1.2 Problem Statement

Matching HAV driving style to passengers' preference could significantly contribute to extending the usage of HAVs. However, existing research is not enough to maintain passenger satisfaction of driving style since too many factors could influence passengers' preference. This research studies user-elicited gesture design to provide design implications for HAV HMI that assists passengers with communicating their intention of adjusting vehicle dynamics simultaneously and straightforwardly, so that HAVs can modify its driving style accordingly to achieve occupants' satisfaction.

1.3 Objectives

The objectives of this research include:

1. to study the intentions, gesture design characteristics, and gesture design mental models for adjusting HAV dynamics;
2. to develop an user-elicited gesture set for adjusting HAV dynamics according to the extent of consensus among our participants;
3. to provide design implications of HAV human-machine interaction.

1.4 Significance

The research outcome could allow designers to create a more natural set of gestures to facilitate passengers to communicate their intention of adjusting HAV dynamics. The interaction could be utilized in both lab-based research and consumer vehicles to obtain passengers' preference for driving behaviors practically. The research could ultimately contribute to matching HAV driving style to passengers' preference and extending the usage of HAVs. More broadly, the results reported in this paper extend our understanding of body gesture interaction for users who are in sitting postures and inside a vehicle context.

1.5 Research Framework, and Outcomes

The study was based on user-elicitation gesture design method that immersed participants in HAV riding scenarios with a virtual reality (VR) simulator and elicited their gesture design for adjusting vehicle dynamics in HAV. The HAV driving scenarios, stemming from the literature on future HAV use cases and HAV ride plots, consist of three different road profiles and 15 discomfort-inducing plots. Participants were required to perform gesture interaction when they felt unsatisfied with the vehicle dynamics while experiencing the scenarios, report their interaction intentions and rationale of their gesture design after experiencing the scenarios, and draw down their interface need if there was.

The user test (N=12) produced five kinds of intentions, at least one gesture design accompanied by explanations for each intention from each participant, and 12 sets of HMI design sketches. Based on the analysis of collected data, a taxonomy of whole-body gesture interaction for adjusting HAV dynamics was proposed. It was demonstrated that consensus existed among the participants on the gesture design. According to the consensus extent, an end-user generated gesture set was constructed. This paper highlights the implications of this work to the design of HAV HMI that assists passengers with communicating their intention of adjusting vehicle dynamics. Figure 3 presents the framework of this study along with the key outcomes of each phase.

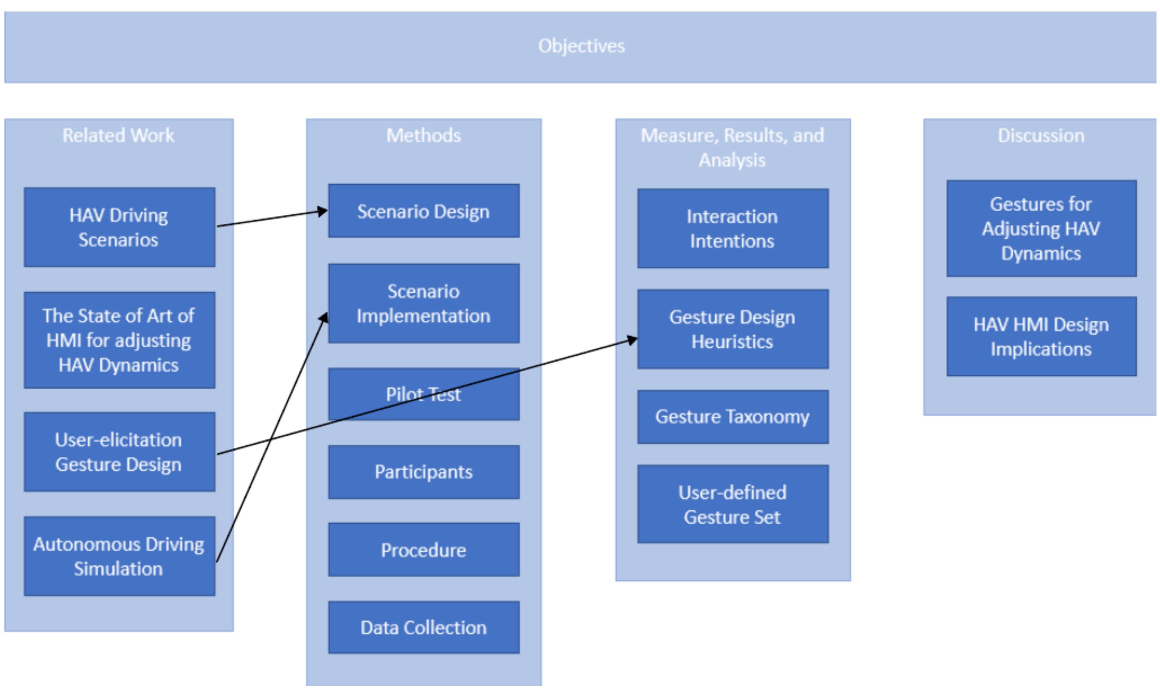


Figure 3 Research framework.

CHAPTER 2. RELATED WORK

The literature review consists of four parts:

1. To comprehensively collect the intention and gesture design of adjusting HAV dynamics, the HAV simulator should inspire participants with the scenarios that represent adequate common and provocative HAV riding plots. Therefore, the author reviewed the literature about HAV use cases, traffic scenarios, and driving behaviors to inform the virtual scenario configuration.

2. The author studied the state of art of HMI for adjusting HAV dynamics and thus selected the modality of whole-body gesture as our research focus because that it had advantages over other modalities for such interaction need and the feasibility empowered by in-vehicle occupant sensing technology, and it is under-researched in literature for such use case.

3. The author studied gesture design techniques to guide the user testing design.

4. Because of the difficulties of conducting user study on real roads, the author explored and compared the simulation methods, and determined the simulation scheme according to the requirements of this study.

The following sections present the literature review work in detail.

2.1 HAV Driving Scenarios

2.1.1 Representative HAV Use Cases

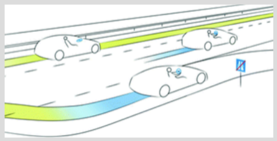
Wachenfeld et al. (2016) proposed four distinguishing use cases of HAVs to serve as proxies for the countless use cases generated from the combination of autonomous driving features, sceneries, and service models. Three of the use cases, which have passengers on the vehicle, include (see Figure 4):

Interstate Pilot Using Driver for Extended Availability: HAVs can fully take the driving task when entering interstate and coordinate the handover to the driver when exiting interstate or being deactivated. This use case has simple scenery, limited dynamic objects, and high velocity.

Full Automation Using Driver for Extended Availability: In a permitted traffic area, drivers can always hand over the driving task to the HAV. This use case corresponds strongly with today's passenger vehicle usage, in that the driving task is almost completely delegated to the HAV while the traditional main user and driver still participate in the journey.

Vehicle on Demand: The driving robot receives the requested destination from occupants or external entities (users, service provider, etc.), to which the vehicle proceeds autonomously. Humans do not have any option to take over the driving task. The human can only indicate the destination or activate the safe exit. This use case enables a wealth of different business models even that goes beyond the pure transportation task.

As shown in Figure 4, the use cases cover various road profiles and effect occupants' accessibility to controllers.



	Interstate Pilot	Fully Automation in Permitted Areas	Vehicles on Demand
Example	i-75	Atlanta Midtown	Klaus Parking
Velocity	High	Moderate	Low-Moderate
Traffic	Light - Moderate	Moderate - Heavy	Moderate- Heavy
Map Complexity	Simple	Complex	Moderate
Accessiblility to Controllers	Yes	Yes	No

Figure 4 HAV use cases.

2.1.2 HAV Driving Plots

Afterward, the author looked for provocative HAV driving plots for configuring the virtual scenarios. Brown's study (Brown & Laurier, 2017) suggests common discomfort-causing HAV driving behaviors such as lurching, crossing complex intersections, entering the wrong way, speeding on corners, and being cut by other vehicles based on the review of 69 clips of passenger-perspective videos of riding HAVs from YouTube. Karjanto et al. (2016) carried the experimental investigation of driving style preference based on the driving scenarios consisting of passing junction, speed hump, and corner. Elander, West, and French (1993) defined the concept of driving style as a habitual way of driving, which includes a person's preference of velocity, their conditions for overtaking, preferred headway distance and how strictly they abide traffic laws. Other studies also explicitly mention the importance of acceleration behavior, which is a natural result of different preferences for velocity changes, in differentiating driving styles (Bellem et al., 2016; Karjanto et al., 2017). The work of Tomita, A. et al. (2017) creates discomfort ADB by regulating maximum speed, acceleration/deceleration pattern (linear or exponential). Inductively collecting and categorizing the plots in prior work led to an inventory of plot elements for the user testing scenarios, which contains three dimensions (Table 1):

- The elements in Vehicle Dynamics dimension describe the individual HAV movement.
- The elements in External Environment dimension describe the physical relationship between the HAV and surrounding objects including infrastructure and other road users.
- The elements in Road Manner and Rules dimension describe the moral relationship between the HAV and external environment and other road users.

Table 1 The inventory of elements in HAV riding scenarios.

Dimensions	Elements
Vehicle Dynamics	Velocity Acceleration/Deceleration Path
External Environment	Distance Distance Change
Road Manner and Rules	Speed Path Road Right

2.2 Human-machine Interaction Design for Adjusting HAV Dynamics

The author reviewed existing HMI research about adjusting HAV dynamics that more or less addresses the new context in HAV that the driver has a decreased controllability of driving behavior, less awareness of traffic situation, weakened driving skills, limited effort for driving task.

Hammar & Karlsson (2015) proposed a multi-touch gestural system for semi-autonomous driving, which enables the driver to influence the driving by giving instructions, such as change lane or take next exit/turn to the vehicle while it is in autonomous mode, see Figure 5 (a). They argue that the users seem to prefer gestures which resemble the movement of the vehicle, and the single finger gestures are preferred rather than multi-touch, and thus the gestures should be designed to be as simple as possible in terms of the gestural motion.

Tscharn, Latoschik, Löffler, & Hurtienne (2017) proposed a multimodal input technique for Non-critical Spontaneous Situations in autonomous driving scenarios such as selecting a parking lot or picking up a hitchhiker, see Figure 5 (c). Speech and deictic (pointing) gestures were combined to instruct the car about desired interventions which include spatial references to the current environment. The speech and pointing gesture input was compared to speech and touch-based input in a user study with 38 participants. The evaluation showed that speech and pointing gestures are perceived as more natural, intuitive and less cognitively demanding compared to speech and touch.

A joystick-like haptic interface named Stewart was developed to allow users to sense and influence the behavior and intentions of HAVs (Ng, Brewster, Beruscha, & Krautter, 2017), see Figure 5 (a). It can express the next step of the HAV with its movement. And the user can also express their instructions of HAV driving by moving it. A form of haptic interaction was chosen since it was believed that it would be a non-obtrusive way to communicate the car's intention and also provide opportunities to indirectly influence the car's driving behavior.

Therefore, it can be seen that in terms of communicating the intention of adjusting HAV dynamics, gesture interaction is a natural, intuitive way of indicating driving-related information including direction, position, extent, and dynamics. However, most research focus on hands only and limited research study body gesture, which make extended use of the full range of human capabilities (England, 2011; Fogtmann, Fritsch, & Kortbek, 2008), for in-car interaction. In HAVs, drivers can move more freely without the restrictions of keeping hands on wheels, foot on pedals (SAE International, 2015). Therefore this study focuses on body gesture interaction.

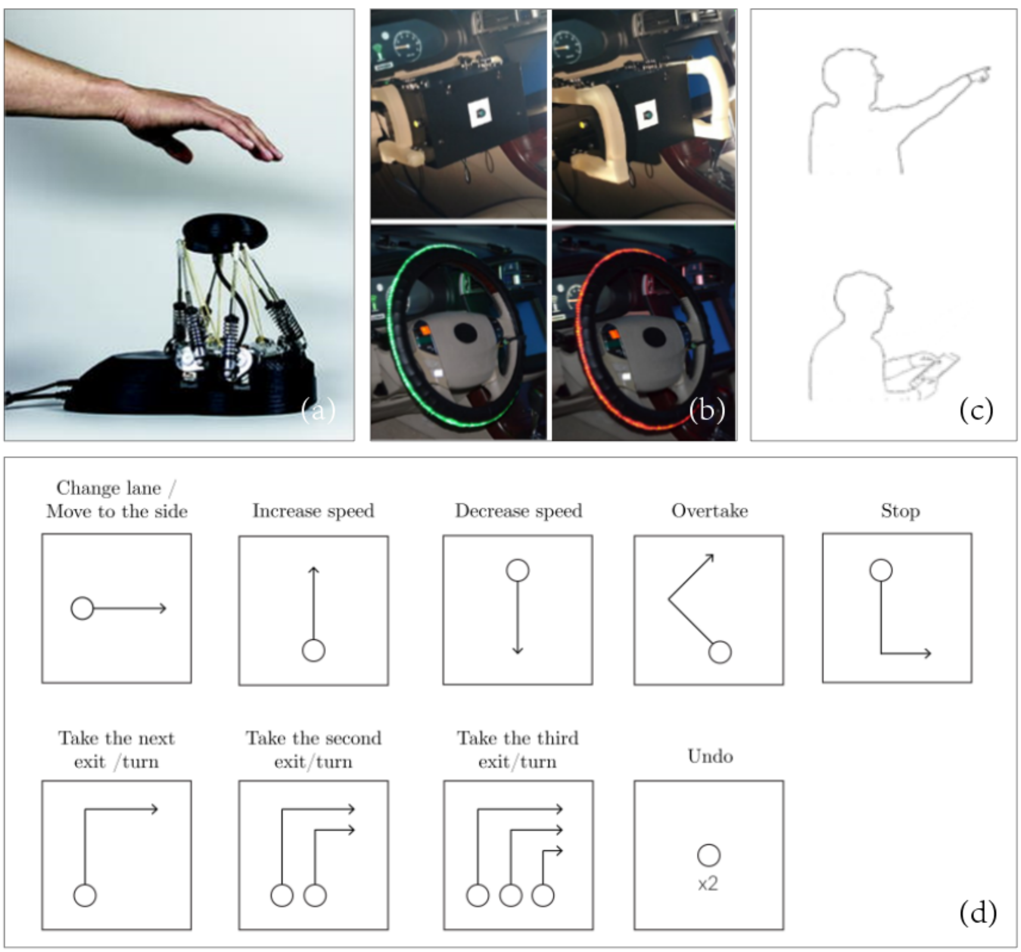


Figure 5 Prior art on adjusting HAV dynamics.

2.3 Gesture Design Methods

Considering the diversity of gestures and the lack of design guidance on gesture-based interaction, researchers have been exploring a clear and systematic design process that can help to improve the quality of gesture-based interaction. The process mostly applies a user-centered approach in the process of gesture development, including the requirement gathering and functionality definition, gesture elicitation, gesture design and usability evaluation (Bodiroža, Stern, & Edan, 2012; Stern, Wachs, & Edan, 2006; Wu, Wang, & Zhang, 2016). A considerable amount of literature argues that involving actual users, especially in the environment in which they would use the final systems, often leads to improved user experience and user satisfaction.

Especially in the early stage of designing gesture interaction for a new application, user-elicited gesture design, the approach of prompting users with the effects of an action and having them perform a gesture, has been commonly used (Vatavu & Wobbrock, 2015; Wobbrock, Aung, Rothrock, & Myers, 2005; Wobbrock, Morris, & Wilson, 2009; Rädle et al., 2015; Ruiz, Li, & Lank, 2011). Wobbrock et al. (Morris, Wobbrock, & Wilson, 2010) proposed the user elicitation method as one way to help understand users' perception and mental models about interaction gestures and elicit design input from users and finds consensus sets of gestures among users' proposed designs. They compared the gesture design generated by three gesture design experts and 20 participants and argued that the group of participants generated better gesture set in terms of quality and users' preference. Therefore, this study applies the user-elicitation gesture design approach.

Despite the usefulness of the user elicitation method for generating user input, there remains the problem of legacy bias, that is, users' previous experience with interfaces could cause bias in their creation, thus fail to explore more potential new designs. To reduce legacy bias, Morris et al. (Morris & Wilson, 2009) proposed three techniques to improve this method: production, priming, and partner. Production forces participants to generate more proposals than the most readily available one. Priming works by showing participants examples of new technologies to inspire creativity. Partner requires users to participate in an elicitation study in groups receiving feedback from partners and improvising.

2.4 Autonomous Driving Simulation

Driving simulators have been extensively used across automotive HMI research (Alvarez, Rumbel, & Adams, 2015; Bellem et al., 2017; Craighead, Murphy, Burke, & Goldiez, 2007; Gold, Körber, Hohenberger, Lechner, & Bengler, 2015; Payre, Cestac, & Delhomme, 2016; Siebert et al., 2013; Slob, 2008, 2008; Sportillo, Paljic, Ojeda, Fuchs, & Roussarie, 2018; Taheri, Matsushita, & Sasaki, 2017) and validated by a considerable body of literature (Tudor, Carey, & Dubey, 2015; Underwood, Crundall, & Chapman, 2011; Walch et al., 2017). They provide the opportunity to efficiently implement critical scenarios that are ethically and practically not possible to evaluate on real roads, especially in the domain of highly automated driving, which is at higher risk of harming participants due to its insufficient development. They also improve researchers' controllability over testing scenarios and enables replicable test scenarios. They thereby enable rapid and safe empirical exploration of human reaction to various driving situations. The selection of simulation scheme for this study is based on the user test requirements, comparison of existing driving experience simulation techniques in terms of fidelity and cost. The study requires high immersion of surrounding situations and hazards so to inducing discomfort of ADB to passengers, thus inspire their natural and realized reactions close to that on real roads. It requires no controller system in contrast to most user studies on lower-level autonomous vehicles, which involve driving-related tasks.

Building on the proposal by Jelmer (Slob, 2008) and other research of driving simulator techniques apparatus, we classify and compares driving simulation techniques, emphasizing visual simulation, with an assessment on fidelity and cost. A typical driving simulator consists of 4 elements (Craighead, Murphy, Burke, & Goldiez, 2007; Slob, 2008), see Figure 6. Visual simulator displays surrounding scenes to generate users' illusions of self-motion. It could be a 2D, 3D screen or a VR head mount display. The fidelity assessment on visual simulator depends on the angle of view, and if the scene angle could align with the vehicle angle. Motion simulator provides motion feedback to enhance immersion. The fidelity assessment of motion simulator depends on the dimension of freedom. Craighead, J. et al. (Craighead et al., 2007), building on prior work by Alexander (Alexander, Brunyé, Sidman, & Weil, 2005), identified three available robotics simulators that meet the fidelity requirements: the Unity game engine, the X-Plane flight simulator, and the Microsoft Robotics Studio. Among them, Unity is much easier to use.

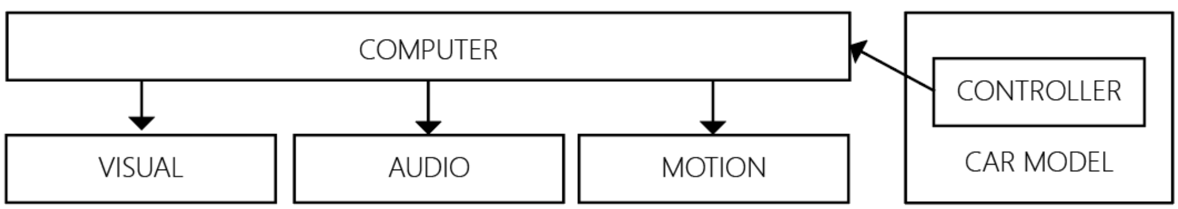


Figure 6 Conceptual diagram of driving simulators.

The author selected VR HMD along with audio simulation as the simulator scheme and excluded motion simulator, see Figure 7 and Figure 8. This scheme could dissociate participants to a higher degree from the real world compared to 2D or 3D screens. It also allows for reducing the fidelity of the physical car model. The similar setting has been used and validated by Underwood et al. (2011). They compared participants' detection of and reaction to hazards while driving on real roads, watching 2D film clips, and VR driving simulator. They conclude that driving in the VR simulator can deliver representative results for the detection of and reaction to hazards.

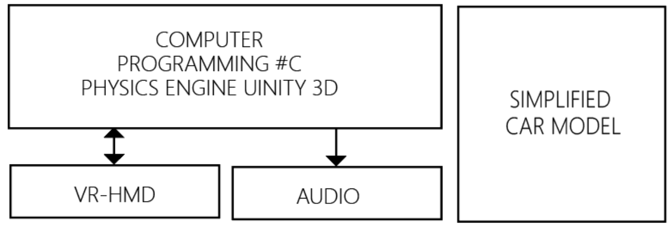


Figure 7 Conceptual diagram of the HAV simulator.

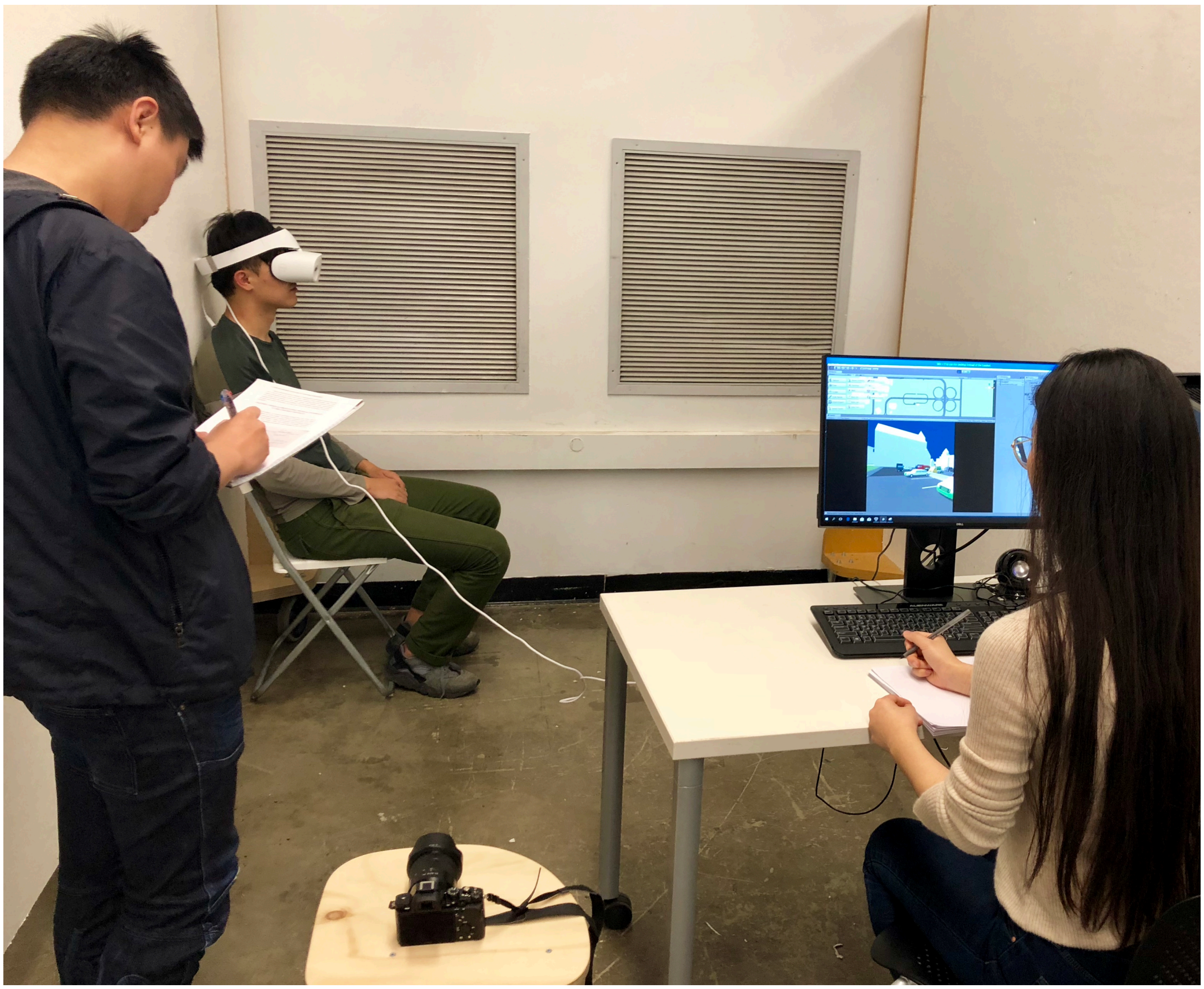


Figure 8 Layout of the HAV simulator and testing environment.

CHAPTER 3. METHODS

Participants were immersed in virtual reality HAV ride scenarios containing discomfort-inducing plots and asked to design and perform a gesture that could be used to express their discomfort caused by the ADB. As the goal of the study was to elicit a set of end-user gestures, we did not want participants to focus on recognition issues or current in-car sensing technology, and we want to avoid the bias from participants' prior knowledge on the in-car sensing technology. As a result, no recognizer feedback was provided to participants during performing the gestures. We also encouraged the participants to ignore recognition issues by instructing them to treat the in-car environment as a "magic room" capable of understanding and recognizing any gesture they might wish to perform. The rationale for these decisions was the same as the rationale expressed in Wobbrock et al.'s surface gesture work (Morris et al., 2010) and Ruiz et al.'s motion gesture work(Ruiz et al., 2011). Specifically, the author wished to remove the gulf of execution from the dialog between the user and the system, i.e., to observe the users' unrevised behavior without users being influenced by the ability of the system to recognize gestures.

The study is based on user-elicitation gesture design method that immerses participants in HAV riding scenarios with a virtual reality (VR) simulator and elicits their gesture design for adjusting vehicle dynamics in HAV. The HAV driving scenarios, stemming from the literature on future HAV use cases, driving styles, and quantitative living behaviors, consist of three distinguishing road profiles and 15 discomfort-inducing plots. Participants are required to perform gesture interaction if unsatisfied with the vehicle dynamics in plots while experiencing the scenarios, report their interaction intention and rationale behind their gesture design after experiencing the scenarios, and then draw down their interface need if there is. To observe the users' undefined behavior without users being influenced by the ability of the system to recognize gestures, no recognizer feedback was provided to participants during performing the gestures. The participants were instructed them to treat the in-car environment as a "magic room" that is capable of understanding and recognizing any gesture they might wish to perform.

3.1 Scenario Design

3.1.1 HAV model in User Testing

The HAV model was decided based on desktop research on design trends of HAVs including models from Waymo, Tesla, Mercedes Benz, Volkswagens, shown in Figure 9. The HAV is a compact car model with removed steering wheel and pedals. Participants were seated in the front right seat because it might intensify participants' feeling of passengers instead of drivers.

Figure 9 Mood board for HAV design.

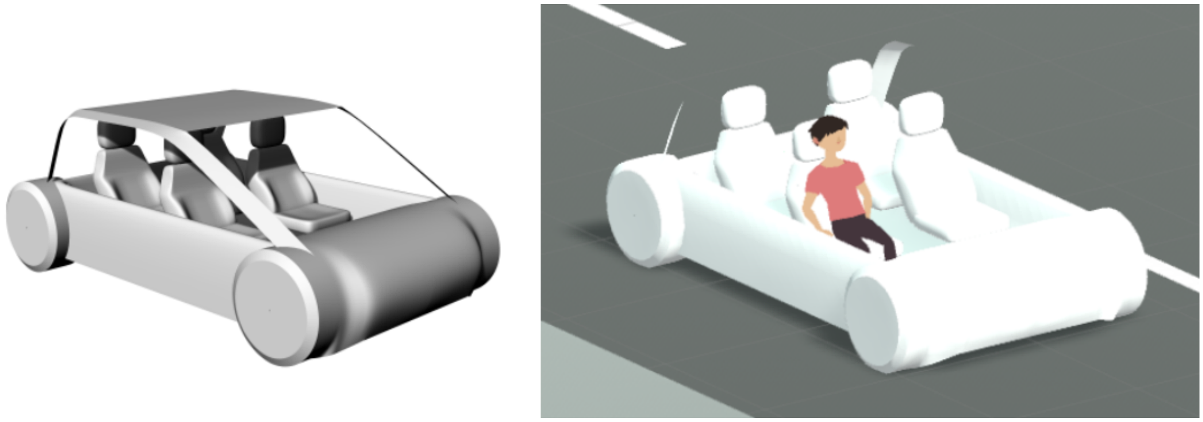


Figure 10 HAV design.

3.1.2 Scenarios

Table 2 elaborates the context of the scenarios. Appendix.5 shows the 3 VR scenarios with the vehicle paths and screenshots of the key plots. The scenario design was informed by prior surveys of HAV use cases and HAV ride plot elements. The three scenarios designedly correspond to the three road profiles. Each revised scenario, containing five key plots with 10-second intervals in between, is about 1-minute long. The three scenarios together could cover most HAV ride elements.

Scenario1: Scenario 1 is on interstate with simple scenery, limited dynamic objects, and high driving velocity ranging from 20 mph to 70 mph. It contains the plots of speeding, turning, lurching, and sharp braking.

Scenario 2: Scenario 2 is on urban roads with heavy traffic situation and moderate driving velocity ranging from 20 mph to 50 mph. It contains the events of cutting in vehicles, passing, and braking for obstacles.

Scenario 3: Scenario 3 is in a parking lot with light traffic situation and low driving velocity ranging from 0 to 25 mph. It contains the plots of yielding, stop sign, and parking.

Table 2 Scenario description.

	Plots	Description
Scenario 1	1. Curve	Lateral acceleration
	2. Speeding	Velocity
	3. Downhill	Vertical/longitude acceleration
	4. Curve	Lateral acceleration
	5. Stop	Longitude acceleration/headway distance
Scenario 2	1. Cut-in	Headway distance
	2. Change lane	Lateral acceleration
	3. Cut-in	Headway distance
	4. Change lane	Lateral acceleration
	5. Stop	Longitude acceleration
Scenario 3	1. Yield	Road right
	2. Speed up and down	Acceleration
	3. Yield	Road manner
	4. Yield	Road manner
	5. Park	Road manner

3.2 Scenario Development

The VR riding simulation has been implemented using Unity 3D game engine (2017.3.1version) programmed by the C# programming language, and a Dell Visor Virtual reality headset powered by Windows Universal Platform as the display device along with earphone. During the VR ridings, participants were sitting on a stationary chair wearing the HMD. Two cameras were recording their reactions from the front and right direction. The author and an assistant were sitting in front of a computer, monitoring participant reactions, VR scenarios, and meanwhile taking notes.

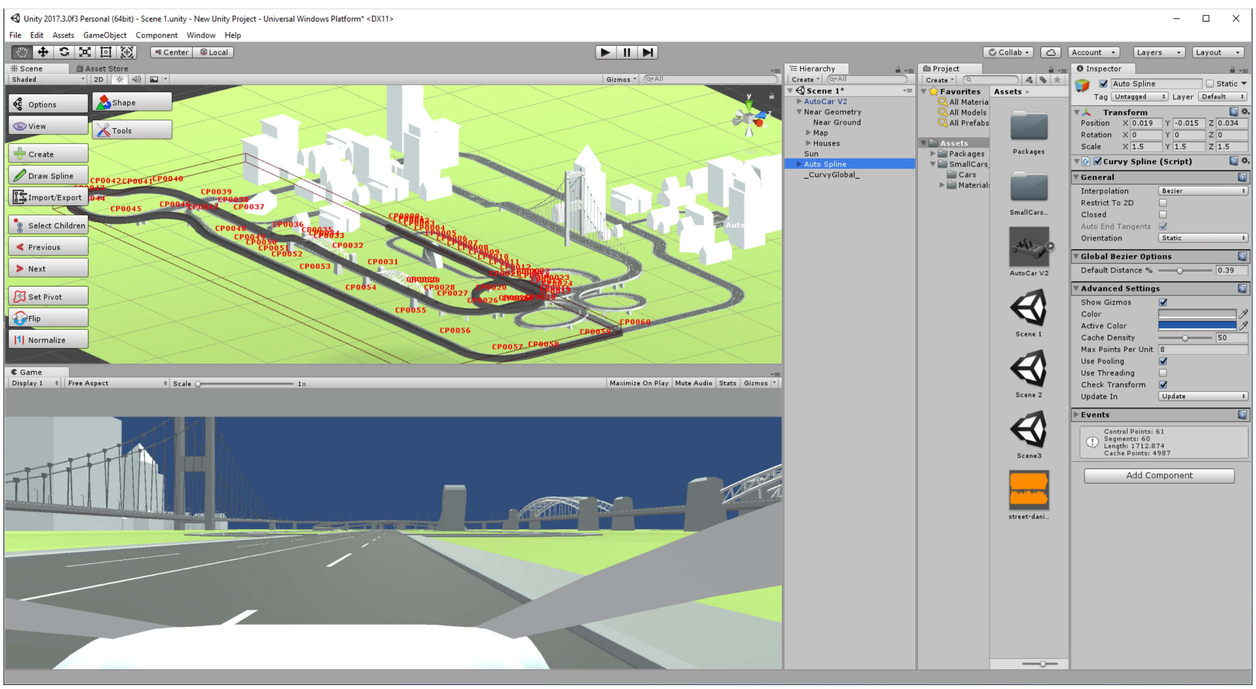


Figure 11 Scenario development in Unity 3D.

To guarantee the quality of user testing results, the VR scenario design and development followed the guidelines for avoiding nausea and improving immersion provided by Unity (2017). Low-poly visual style was selected because it could balance smoothness and fidelity. The guidelines suggest to create something relatively static within users' sight, therefore a static windshield frame, like the static dashboard in racing games, was tested. However, it turned out to decrease users' immersion, so this suggestion was not taken.

3.3 Pilot Test

To improve the reliability and effectiveness of the scenarios, pilot tests were conducted with 3 participants who were experts in UX design, user research, or autonomous driving service design. The pilot test led to the following modifications. The dynamics parameters were adjusted to be more provocative. A warm-up session prior to the formal test was added for adjusting participant position in the virtual vehicle and familiarizing participants with VR environment. The warm-up scenario is 1-minute long, including changing speed, making turns and encountering other traffic. Regarding formal session modification, the intervals between discomfort-inducing events were prolonged to give participants adequate time to think about and react to the present event and to refresh for the next one. An avatar of the participant was placed on the seat. It enabled participants to see "their" body when looking around, helped participants locate themselves in the virtual car, and avoided the strange feeling of a disappeared body.

3.4 Participants

Grasping the concept of adjusting the HAV dynamics with gestures arguably requires that the users have some experience with taking or driving cars. Therefore, participants were recruited among those who indicated that they used cars as their primary transportation. However, those with much more experience with gesture controlling than the normal population were not included. 12 participants (6 males and 6 females), aged from 22 to 29 (*M*=24.76, *SD*=2.75), volunteered their time (*M* =24.47 min, *SD*=12.77, *Min*=20 min, *Max*=58 min) for this study. Participants' driving experience ranged from 0 to 7 years (*M*=2.75, *SD*=2.52). IRB approval was obtained ahead of the experiment.

3.5 Procedure

Upon arrival at the study location, participants got an introduction about the test, reviewed and signed Informed Consent Form and completed Demographics Questionnaire. Participants then had an opportunity to get familiar with the test environment including the seat, virtual reality(VR) head-mounted display (HMD), and VR scenarios with the researcher's guidance. Following the warmup session, participants were instructed that they would be a passenger sitting on the front right seat of the HAV that would pick up and drop off them at various locations in the virtual environment. They were told that the HAV could completely operate the safe driving but could not guarantee comfort driving style. Moreover, they should communicate their intentions of adjusting vehicle dynamics by gestures when they were not satisfied with the HAV driving behavior. They could use head, torso, hands, feet or any other body parts they preferred. They were encouraged to follow the think-aloud protocol while experiencing and gesturing. The formal VR experiencing consisted of 3 different scenarios, each followed by a 5-minute break for rest and retrospective interview. The formal sessions were recorded by both video and experimental observation. Then, participants were requested to complete rating scales for VR experience and car driving behavior. Finally, participants joined a design session. They were assisted by researchers to draw out their ideal interface for supporting their gestures on the Design Template.

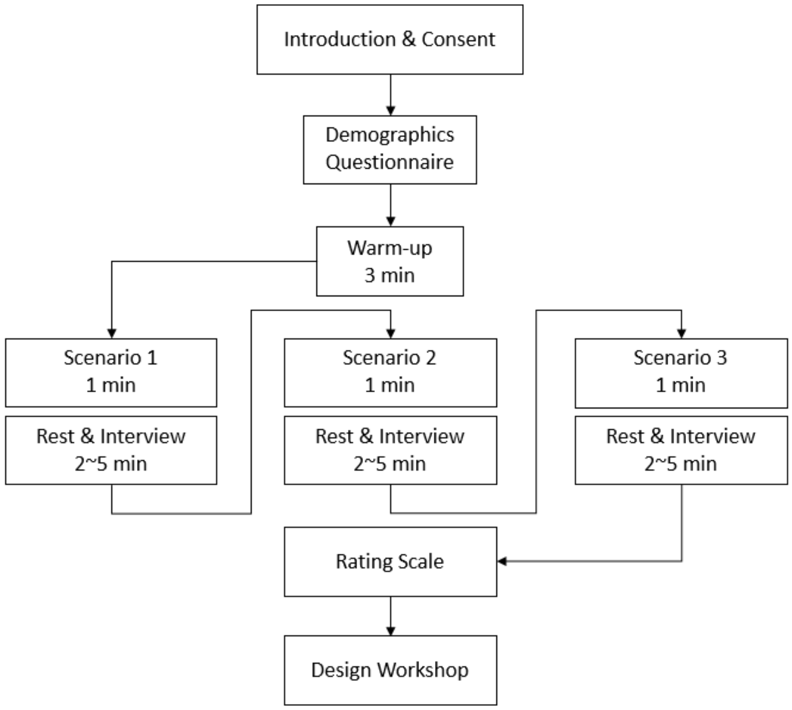


Figure 12 User testing procedure.

3.6 Data Collection

Before VR experiencing, participants were requested to complete the ***Demographics Questionnaire*** about their age, gender, and experience in VR, HAV, and gesture interaction. During the formal session, the researchers kept observing and marking down participants' gestural performance including utilized body parts and patterns on the ***Test Record Form***. During the retrospective interview, researchers recapitulated and discussed the gesture design with participants, the discussion identified if the gestures were intended, and revealed their interaction intentions and the designing rationale. The unintended actions were excluded. Besides, participants' actions were videotaped from the front and left-hand directions for the recheck at low-speed playback mode in Final Cut Pro. In the design workshop session, the researchers interviewed participants about their ideal interfaces, including forms, positions, and interaction modalities based on the ***Retrospective Interview Script***, meanwhile assisted them to draw down on the ***Design Template***.

CHAPTER 4. RESULTS

The results include five kinds of intentions, at least one gesture design accompanied by explanations for each intention from each participant, and 12 sets of HMI design sketches. Based on the analysis of collected data, we propose a taxonomy of whole-body gesture interaction for adjusting HAV dynamics. It could be demonstrated that consensus existed among the participants on the gesture design. Based on the consensus extent, an end-user generated gesture set was constructed.

4.1 Interaction Intentions

Participants' intentions of adjusting HAV dynamics (shown in Table 3) were identified using the interview transcripts and categorized into three groups: the speed-related, the direction-related, and referring to other objects. An intention is speed-related if it involves adjusting the speed, including speed up, slow down and stop, such as expressions like "slow down", "too fast" "stop", "yield", "give way to", "brake is too sharp" and "wait until". An intention is direction-related if it contains directional information such as expressions like "turn right/left", "keep forward". The intention of referring other objects includes expressions such as "it's about to hit …", and "move away from".

Table 3 Categories of passengers' intentions of adjusting the HAV dynamics.

		Examples
Speed	Speed up	P3: "The **brake is too sharp**"
	Slow down	P2: "**Slow down**!" P4: "It's driving **too fast**."
	Stop	P1: "**Stop, stop, stop**!" P7: "**Wait** here, proceed after that car moves." P11: "There is a car coming, we should **give right-of-the-way** to it."
Direction		"It's lurching, **go straight**, keep in the center of the lane." "That's too close to the curb, **turn left** a little bit."
Referring to other objects		P1: "That's too close, I want it to **move away from** the wall." P2: "Slow down. It's **about to hit** the leading car." P4: "**Change to the left lane**."

4.2 Gesture Taxonomy

Participant's gesture design for the 5 intentions were extracted with gesture video playback. There were at least 12 design from participants for each intention, and some participants perfomed same gesture design for an intention for more than one times. The participants' interface sketches also supplemented the analysis (see Figure 13). Mostly the designed interface was apparatus for their gestures in the user testing session, for example **P9** performed a pushing hands forward gesture, and sketched an sensing area on dashboard for pressing on. But sometimes, interface sketches presented different interaction design. For example, **P3** performed in-air gestures while experiencing VR scenarios designed a button interface on a handle later, and reported that she thought it's more reliable to interact with physical touch. In that case, the sketch was excluded.

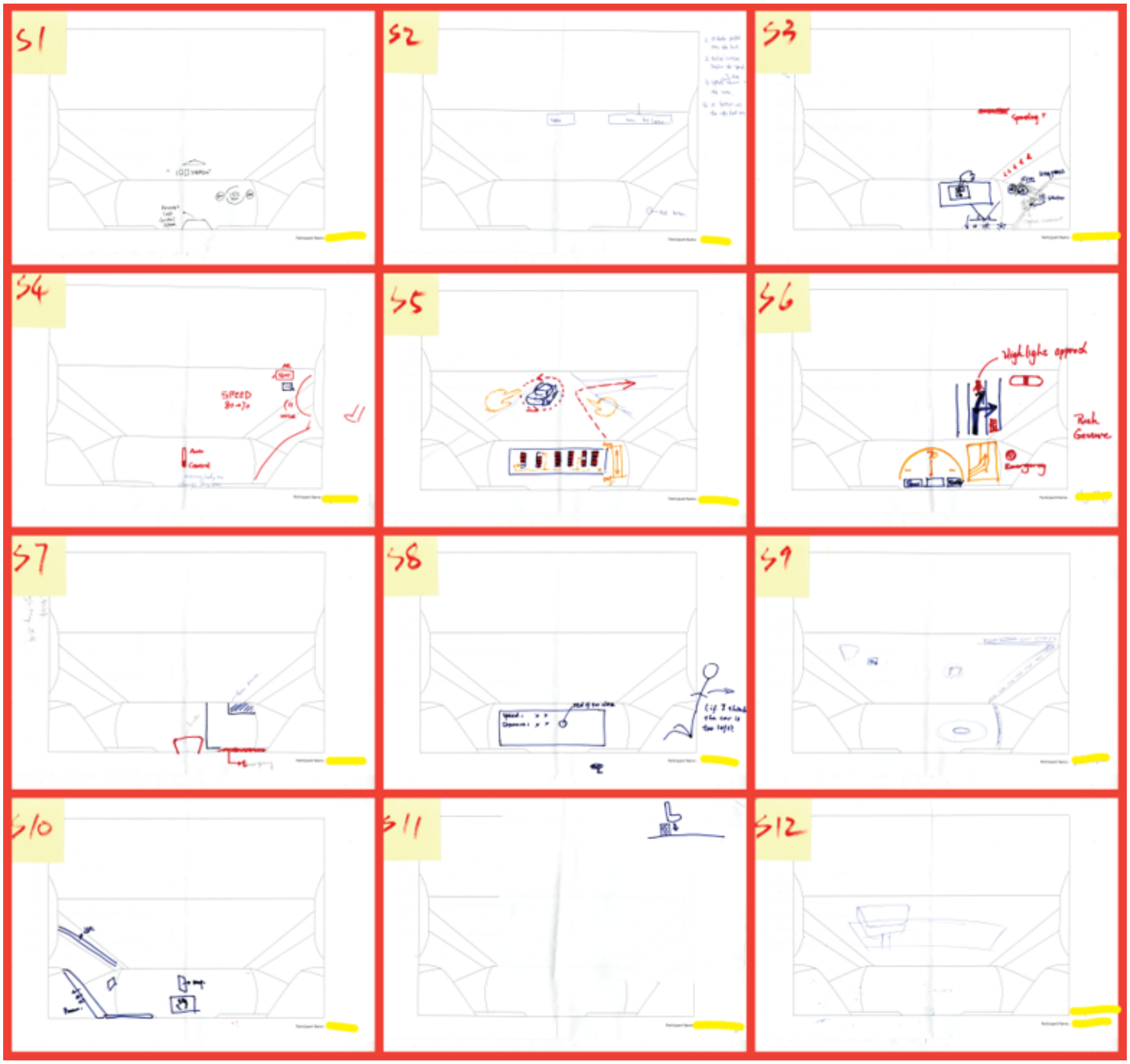


Figure 13 Participants' sketches for their interface need.

A taxonomy for gestures for adjusting HAV dynamics describing the set of dimensions manipulated by our participants as inducting the gestures (see Table 4) was constructed based on a mobile motion-gesture taxonomy framework in prior work of Ruiz (2011). The taxonomy was also built with the consideration that it should inform the future HMI design.

The pattern dimension is a description of how a gesture conveys an intent, whether by adjusting HAV dynamics incrementally or representing the ultimate goal straightforward. Take the gestures for directional intention as an example, P7 leaned her torso to the left to signal that she wanted the car to drive to the left, but she did not consider a certain position where the car should drive to. This gesture was categorized as an incremental pattern. P9 repeatedly pointed in one direction and signaled the car to drive over there. This gesture was categorized as a saltatory pattern.

The body parts dimension describes body parts that participants present a gesture with. The human body into four parts in this study, which are head, torso, upper limb, and lower limb.

The interface dimension describes interior car parts that participants interact with. The interfaces could be real like the seat, virtual in the display, or even imaginary by participants. Besides in-air interaction, some interfaces were commonly needed including dashboard, handle, pedal, backrest. Some participants acted to the parts directly, while the others acted to specific imaginary interfaces like buttons or touch screens on them.

The detail dimension indicates the level of detail of a gesture. The level relates to both involved body parts and the extent of the body part movement. For example, leaning a torso or rising arms were at a low level. Waving hands and stepping by feet were at a moderate level. Hand gestures involving finger posture were at high level.

The complexity dimension relates to whether the proposed gesture is a compound gesture or a simple gesture. A compound gesture was defined as any gesture that could be decomposed into simple gestures by segmenting around body parts dimension in the gesture.

Table 4 **Taxonomy of gestures for adjusting HAV dynamics.**

Dimension	Category
Pattern	Incremental
	Saltatory
Body Parts	Head
	Torso
	Upper Limb
	Lower Limb
Interface	In-air
	Dashboard
	Handle
	Foot Mat
	Seat
Detail	Low
	Moderate
	High
Complexity	Simple
	Compound

The author and assistant separately coded the gesture design of two participants, validated definitions of dimensions and categories against one another to ensure consistency, and continued coding the remainder of the elicited gesture design. A small amount of different coding happened in the level of detail dimension, and the author and assistant reached agreement after discussion. Appendix.6 shows the gesture coding process. Figure 14 illustrates the breakdown of the collected gestures using the taxonomy of gestures for adjusting HAV dynamics. It was designed that for the case that one participant presented more than one gestures for an intention, each gesture was counted as 1 divided by the number of gestures from each participant for each intention. But this case did not happen in this study. For the case that one gesture presented more than one body parts, each body part is counted as 1/ the number of total body parts involved in the gesture. As shown in the figure, gestures tended to be direct, in-context, continuous, moderate amplitude, and simple. Participants used various body parts and interfaces.

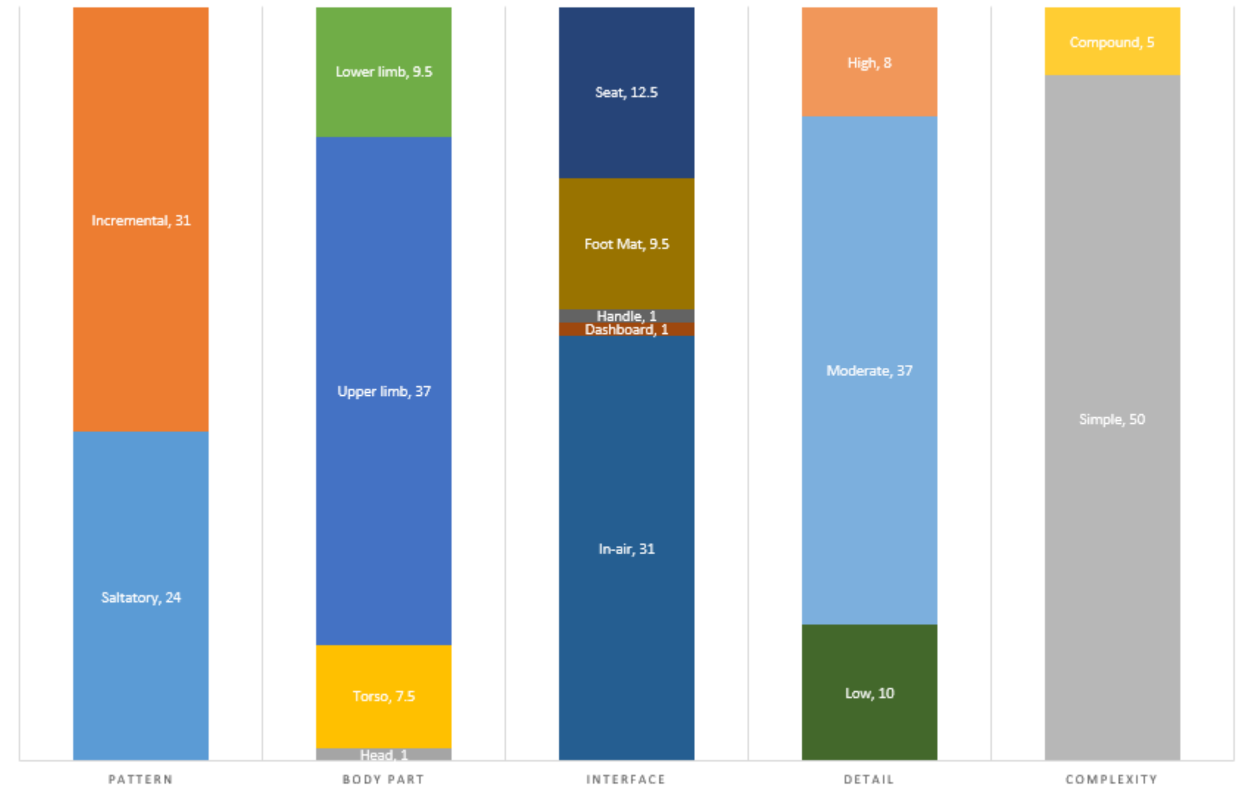


Figure 14 Percentage of gestures in each taxonomy category.

4.3 Mental Model Observations

While the analysis of participant-generated elicitations demonstrate what and how participants employed design elements in their gesture interaction design, transcripts of the recorded interview about participants' rationales of designing the gestures were used to identify why users prefer a specific pattern of gesture interaction. The following paragraphs outline the identified mental models and associated typical action patterns.

Resemble desired vehicle dynamics: Nine participants reported they expected the car could follow the motion of their body parts, for example, they leaned back their torso when wanting the car to slow down, and they lean left when feeling the car was too close to the right road shoulder. The reason of this pattern included that some participants perceived that the HAV was in one unity with their body (P05: “I perceive the intelligent car as a shell of me, it can move along with my body”). Some participants reported it was natural to resemble a movement with some body part to deliver a dynamics message (P02: “I feel like it’s the simplest way for me to describe my idea about how I want it to move”). Torso and hands were mostly observed to resemble the desired dynamics.

References: Four participants reported they communicated their intentions with references from sign languages in the field of traffic guidance and gesture-sensing car. Three participants reported that they were stepping by feet like pressing a pedal in manual driving vehicles to communicate the intentions of slowing down while no participants imagined a steering wheel for directional intention.

The imagination of the HAV: Similar to that a person’s communication style always depends on how the person views themselves, the audience, and the occasion, participants’ communication style varies according to their perception of the HAV. Three participants reported they perceived the autonomous driving system as an intangible human-like driving robot beside them, an invisible drunk driver, or a new driver friend. And they could communicate with it by natural gestures like with a human driver. These participants presented more interaction frequency, and their postures and gestures were in relaxed shapes. The rest of the participants perceived the system as a machine without humanity.

4.4 A User-defined Gesture Set

Identical gesture designs for each intention were grouped together with the gesture taxonomy proposed above. The degree of consensus among the participants for each intention was computed with the process of calculating an agreement score for each task (Vatavu & Wobbrock, 2015; Wobbrock et al., 2005, 2009). An agreement score, A_t, reflects in a single number the degree of consensus among participants. Wobbrock et al. (2005) provided a mathematical calculation for agreement, where:

$$A_t = \sum_{Pi} \left(\left| \frac{P_i}{P_t} \right| \right)^2$$

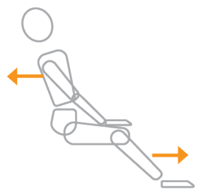
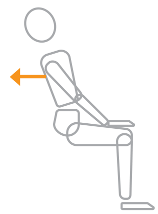
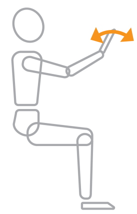
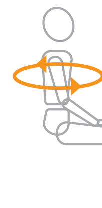
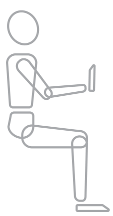
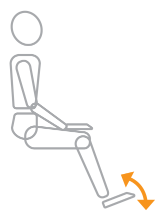
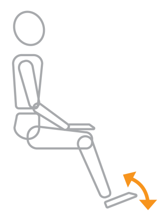
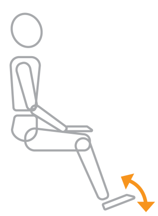
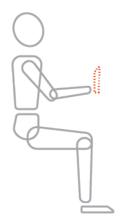
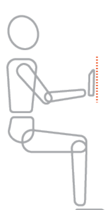
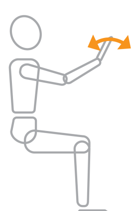
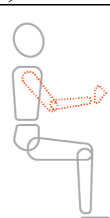
In Equation 1, t is a task in the set of all tasks T, P_t is the set of proposed gestures for t, and P_i is a subset of identical gestures from P_t. The range for A is [0, 1].

As an example of an agreement score calculation, the task stop had 4 groups with sizes of 8, 2, 1, and 1. Therefore, the agreement score for **stop** is:

$$A_{stop} = \left(\frac{|5|}{|11|} \right)^2 + \left(\frac{|3|}{|11|} \right)^2 + \left(\frac{|2|}{|11|} \right)^2 + \left(\frac{|1|}{|11|} \right)^2 = 0.32$$

Figure 15 illustrates the agreement among gesture design for each intention developed by our participants, A.7 shows the calculation process. The average agreement across all intentions was ($\overline{A}$ = .547). Generally, it indicates a good consensus among participants in line with other elicitation studies, e.g., performed by Vatavu & Wobbrock (2015) (A = .32/.28) and Wobbrock et al. (2009)(A = .399). The resulting user-defined set of motion gestures is shown in Table 5.

Table 5 Passenger-inspired gesture set for HAV dynamics evaluation.

Stop(a)	Slow down(b)	Speed up(c)	Direction(d)	Reference objects(e)
 a-1, P=5	 b-1, P= 5	 c-1, P= 7	 d-1, P=5	 e-1, P=7
 a-2, P=3	 b-2, P= 2	 c-2, P= 3	 d-2, P=4	 e-2, P=3
 a-3, P=2	 b-3, P= 2	 c-3, P= 1	 d-3, p=2	 e-2, P=1
 a-4, P=1	 b-4, P= 1			
	 b-5, P=1			

a-1: leaning torso backward and kicking feet forward. Saltatory, torso & upper limb, seat & foot mat, low, compound.
a-2: pushing hands forward. Saltatory, upper limb, in-air, moderate, simple.
a-3: tapping a foot. Saltatory, lower limb, foot mat, moderate, simple.
a-4: pushing hands dashboard. Saltatory, upper limb, dashboard, moderate, simple.

b-1: leaning torso backward. Incremental, upper limb, seat, low, simple.
b-2: tapping a foot. Incremental, lower limb, foot mat, moderate, simple.
b-3: pressing forearm down. Incremental, upper limb, in-air, moderate, simple.
b-4: waving hands backward. Incremental, upper limb, in-air, moderate, simple.
b-5: grasping handle. Incremental, upper limb, handle, moderate, simple.

c-1: waving hands forward. Incremental, upper limb, in-air, moderate, simple.
c-2: tapping a foot. Incremental, lower limb, foot mat, moderate, simple.
c-3: showing a hand gesture. Incremental, upper limb, in-air, high, simple.

d-1: leaning torso to desired directions. Incremental, torso, seat, moderate, simple.
d-2: waving a hand to desired directions. Incremental, upper limb, in-air, moderate, simple.
d-3: pointing to the desired direction. Saltatory, upper limb, in-air, moderate, simple.

e-1: pointing (with fingers) to the referred object. Saltatory, upper limb, in-air, high, simple.
e-2: pointing (with a hand) to the referred object. Saltatory, upper limb, in-air, moderate, simple.
e-3: facing to the referred object. Saltatory, head, in-air, moderate, simple.

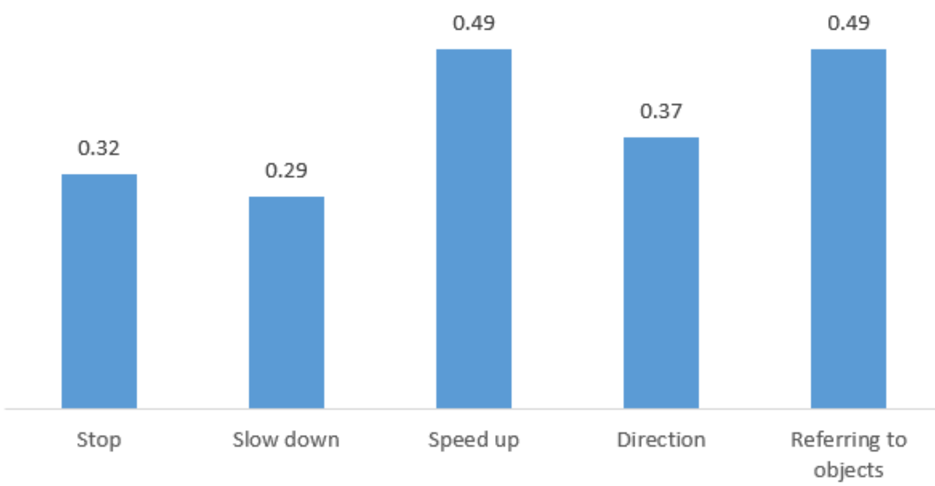


Figure 15 Consensus upon gesture designs among participants for each intention.

CHAPTER 5. DISCUSSION

The results showed five types of intentions, which HAV passengers may have for adjusting the vehicle dynamics, that include speeding up, slowing down, stop, regulating direction, and referring to other objects. The results demonstrated that the consensus of gesture design existed among the participants. The results also presented the characteristics of passenger-elicited gestures for such intentions in terms of patterns, body parts, interfaces, and levels of details and complexity. The following sections discuss the results towards the objectives of implying HMI design for HAV passengers to adjusting vehicle dynamics.

5.1 Implications for HMI Design

Designers could use the results as initial guidelines to design gesture interaction for passengers to adjust HAV dynamics. For example, the results indicated that passengers tended to adjust the dynamics incrementally, so the interaction should allow users to approach the desired state gradually. Most user-elicited gestures were at low or moderate levels of detail and simple, so the interaction should avoid requiring users to perform highly detailed or compound gestures. The results showed that gestures performed with hands and in air took the most percentage of the gesture set. Those performed with lower limb or torso took one-third of the set. Those supported with the interfaces of seat and foot mat took about forty percent of the set. This fact had two folds, on one side, it showed hand and in-air gestures were well preferred and accepted by participants, which was reasonable due to the current gesture interaction state. On the other side, it showed that the other body parts and interfaces also had opportunities to be employed by participants.

The mental models indicated that most participants thought it was intuitive and simple to resemble desired vehicle dynamics with some body parts as a way of communicating their intentions of adjusting HAV dynamics. This finding share similarity with the study done by Hammar & Karlsson (2015) that proposes a multi-touch gestural system for driving control in semi-autonomous driving. It suggested that such kind of gesture pattern could be employed for the gesture interaction of adjusting HAV dynamics. The mental models also showed that participants designed gestures according to their previous experiences such as driving, in-car communication with real people, and observed sign language from traffic controllers. Therefore, designers could use these experiences as resources when designing the gesture interaction. Moreover, the mental models presented that passengers' perceived humanity of the HAVaffected their gesture style. So when designing the HMI, designers should consider not only the gesture patterns but also the overall characteristics of the system.

5.2 Implications for Occupant Sensing System

There are lots of existing techniques on using computer vision to detect driver facial expression and eye tracking data, analyzing drivers' manipulation on steering wheels and pedals to interfere drivers' effect state or driving status. The gesture set identified in this research could provide guidance about how to apply the existing techniques to obtain passengers' preference for driving dynamics. For example, most current car seats equip with pressure sensor matrix to detect occupancy so that car can control indicators and airbag activation accordingly. Further research could explore using the pressure sensor matrix to detect passengers' torso motion and thus interfere their intention of adjusting HAV dynamics.

CHAPTER 6. CONCLUSION

This study produced five kinds of intentions, at least one gesture design accompanied by explanations for each intention from each participant, and 12 sets of HMI design sketches. Based on the analysis of collected data, a taxonomy of whole-body gesture interaction for adjusting HAV dynamics was proposed. It was demonstrated that consensus existed among the participants on the gesture design. According to the consensus extent, an end-user generated gesture set was constructed. This paper highlights the implications of this work to the design of HAV HMI that assists passengers with communicating their intention of adjusting vehicle dynamics.

The study has some limitations. Firstly, the number of participants in this user study was 12, which is smaller than other user-elicitation gesture studies. This might reduce the power of the agreement scores. Secondly, the users chosen for testing in this study were between 22 to 29 years old, which was not a diverse demographic. This study might have produced totally different results with older adults assuming that they might not be as familiar with gesture interaction. Thirdly, this study utilized a low-poly visual style instead of photo-realistic and adopted VR simulator instead of providing a corresponding physical car interior. This might hurt the effectiveness of the simulator.

Further studies would be conducted to improve the body gesture interaction guidelines. A future study would recruit more participants in diverse demographic groups to examine whether there are differences in participants-generated gesture design among participants with different levels of driving experience and perceptions of HAV humanity. We would adopt sensor systems to obtain the quantitative parameters of gestures. Also, we would explore how to distinguish an intended interaction with casual body movement. The simulator would be modified by improving the visual fidelity and adding inertial force simulation, which could be effective and allow participants to feel the vehicle dynamics without observing constantly. This simulator would empower us to study the interaction when participants carrying non-driving related tasks, which they may engage in during real HAV rides. Moreover, we would design, develop, and evaluate interfaces for adjusting HAV dynamics based on the findings from this research. By doing so, we could practice, evaluate, and modify the design guidelines obtained in this study.

APPENDIX A. USER TESTING MATERIAL

A.1 User Testing Manual

BEFORE VR TESTING

To introduce purpose:

This research aims to study human reaction and natural gestures upon different kinds of interaction intentions based on VR simulation environment. The significance of this research includes developing the design guidelines for interventional user interfaces.

To introduce procedures:

If you decide to be in this study, first you will be asked to complete the pre-interaction survey, it will cost 5-10 minutes.

Then you will have an opportunity to become familiar with the equipment, Dell VR118, a VR headset delivering an unparalleled experience with ultimate comfort: You have 5mins to freely explore the VR system with our tutorial, including the virtual environment (VE), simulated vehicle, and system controls.

Following the practice session, you would be a passenger onboard a fully autonomous car that would pick-up and drop-off at various locations in the virtual world; you are encouraged to *intervene if you feel it's necessary for the safety or comfort of yourself. Each scenario would cost about 1 minute. After each scenario there will be a 3-5 minutes break, we will ask you some question regarding your reaction. The whole process will be recorded by both video and experimental observation.*

After the test, you will be invited to an interview.

The total study will take you from 20-30 minutes.

Some people may get a simulator display motion sickness. If you feel any discomfort, please tell at the first time so that we could stop the test.

Sign consent form

Fill out demographics questionnaires

WARM-UP SESSION

Now we're going to start the warm-up session.

To make sure the participant sit and wear devices well

Do you sit well and wear the HMI and earphone comfortably?

To adjust the participant position in a VR environment

Please look around, do you feel that you're sitting inside a car on the front passenger seat? Look up- see the moonroof? Look down - see your legs? Look front- see the windshield and pillars? Can you hear the sound?

To familiarize the participant with car movement in VR

Ok, the car is going to start. It's speeding up, slowing down, making a turn. Please try to express your intention using your gestures and body motion as much as possible, speak aloud your intent if you can.

FORMAL TEST

To start the camera

Are you ready to take a formal test?

To remind and encourage the participant of gesture usage

Please keep in mind that try to express your intent using your gestures and body motion as much as possible, speak aloud your intent if you can.

To keep observing and marking down participants' actions including utilized body parts and patterns on the Test Record Form

To recapitulate participant key action in the after-scenario break, to identify if the actions were intended and caused by the Emergency Events, to inquire about intents and rationale of actions

I saw you ……, were you intended? What caused you to interact?

What's your intent of this action?

Why did you use this body part?

Why did you interact this way?

INTERVIEW

To let the participant rate the overall VR experience and the ADS-DV behavior based on After-test rating scales

To collect the participant needs and design suggestion based on the Design Template.

Do you want to have some control over the car movement?

Why do you need that control?

How do you want to control?

Do you need any driving-related information?

Why do you need this info?

How do you want to be informed?

Could you draw down your idea on the template?

A.2 Demographics Questionnaire

1. Age: What is your age?

2. How many years of diving experience do you have?

• Less than 1 year

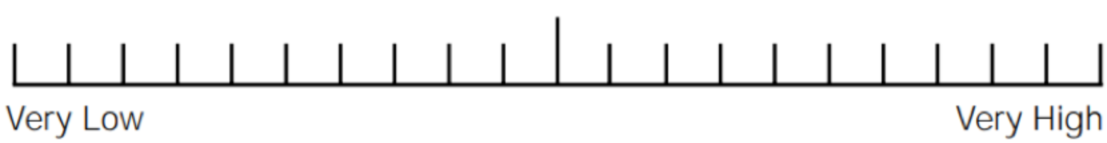
• 1-3 years

• 4-10 years

• more than 10 years

3. How much experience do you have with VR?

4. How much experience do you have with gesture control?



A.3 User Testing Record Form

Participant:	Researcher:	Assistant:	Date:	Time:			
	Head	Torso	Hand	Foot	Intent	Action	Rationale	Notes
Scenario 1								
1. curve								
2. speeding								
3. downhill								
4. curve								
5. stop								
Scenario 2								
1. Cut-in								
2. Change lane								
3. Cut-in								
4. Change lane								
5. Stop								
Scenario 3								
1. Yield & Left turn								
2. Speed up & down								
3. Yield								
4. Yield								
5. Park								
SUM								
Other Notes								

A.4 After Test Rating Scale

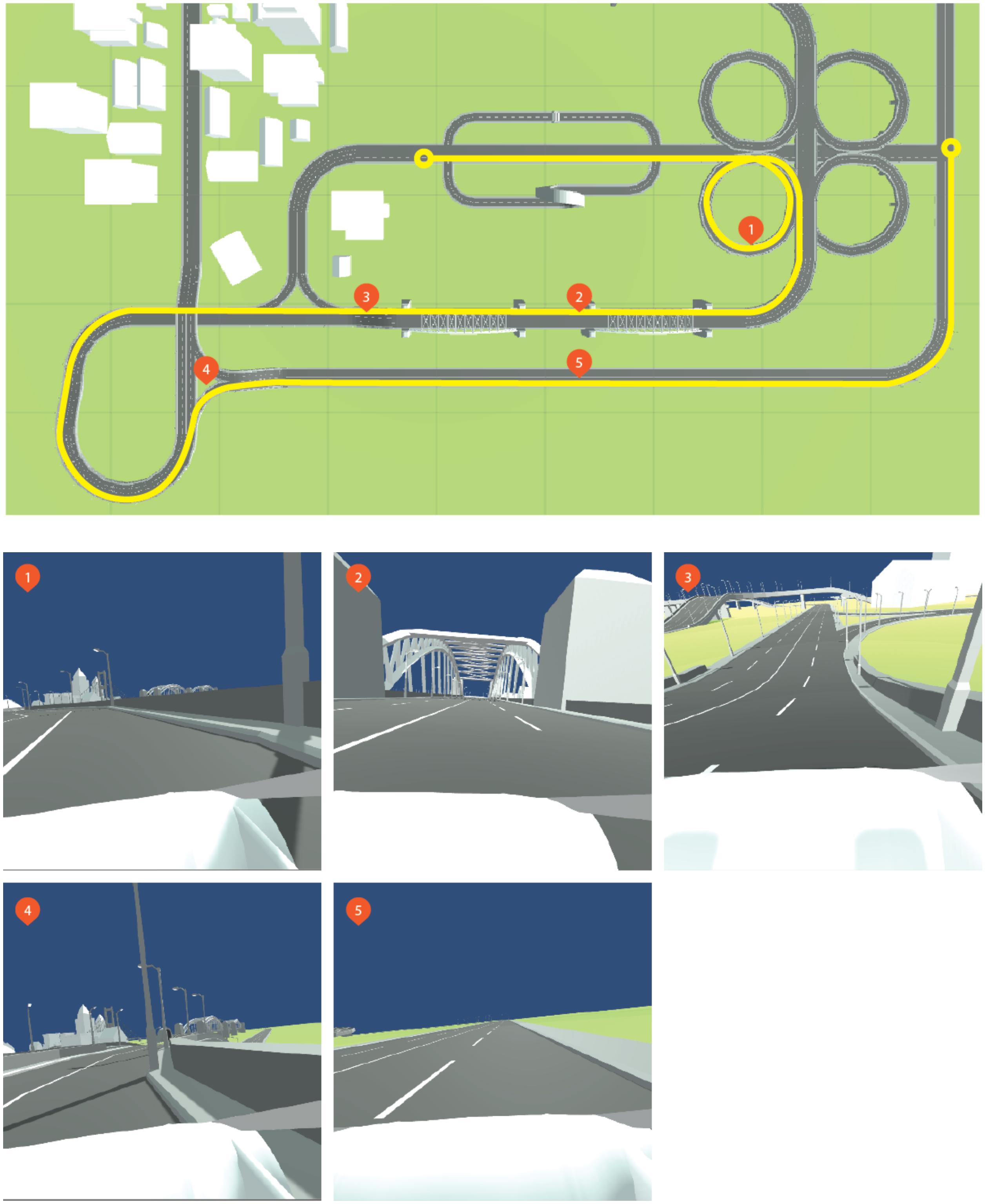
VR Experience

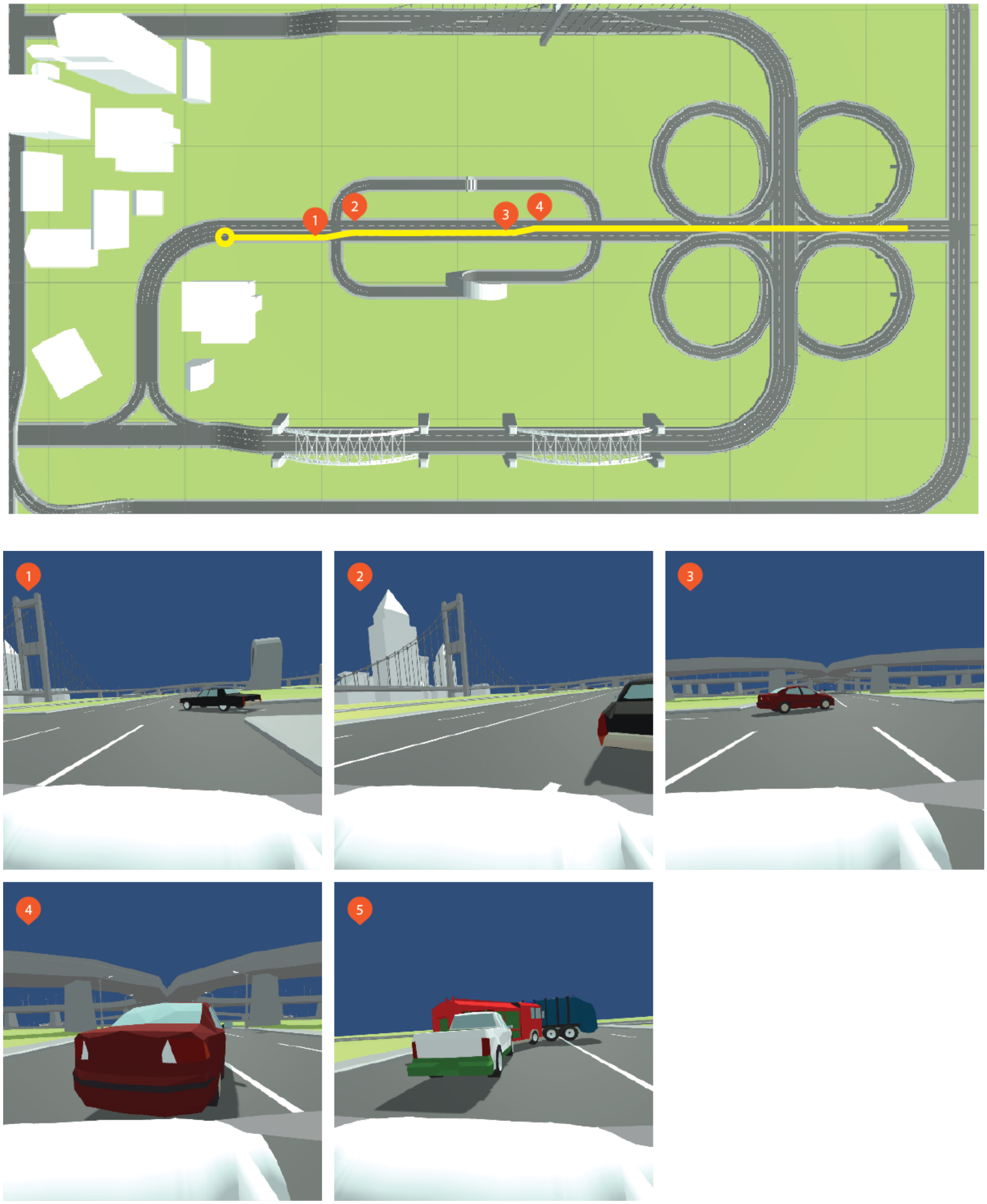
	Very Good				Very Bad
Presence & Immersion					
Interest& Enjoyment					
Comfort					

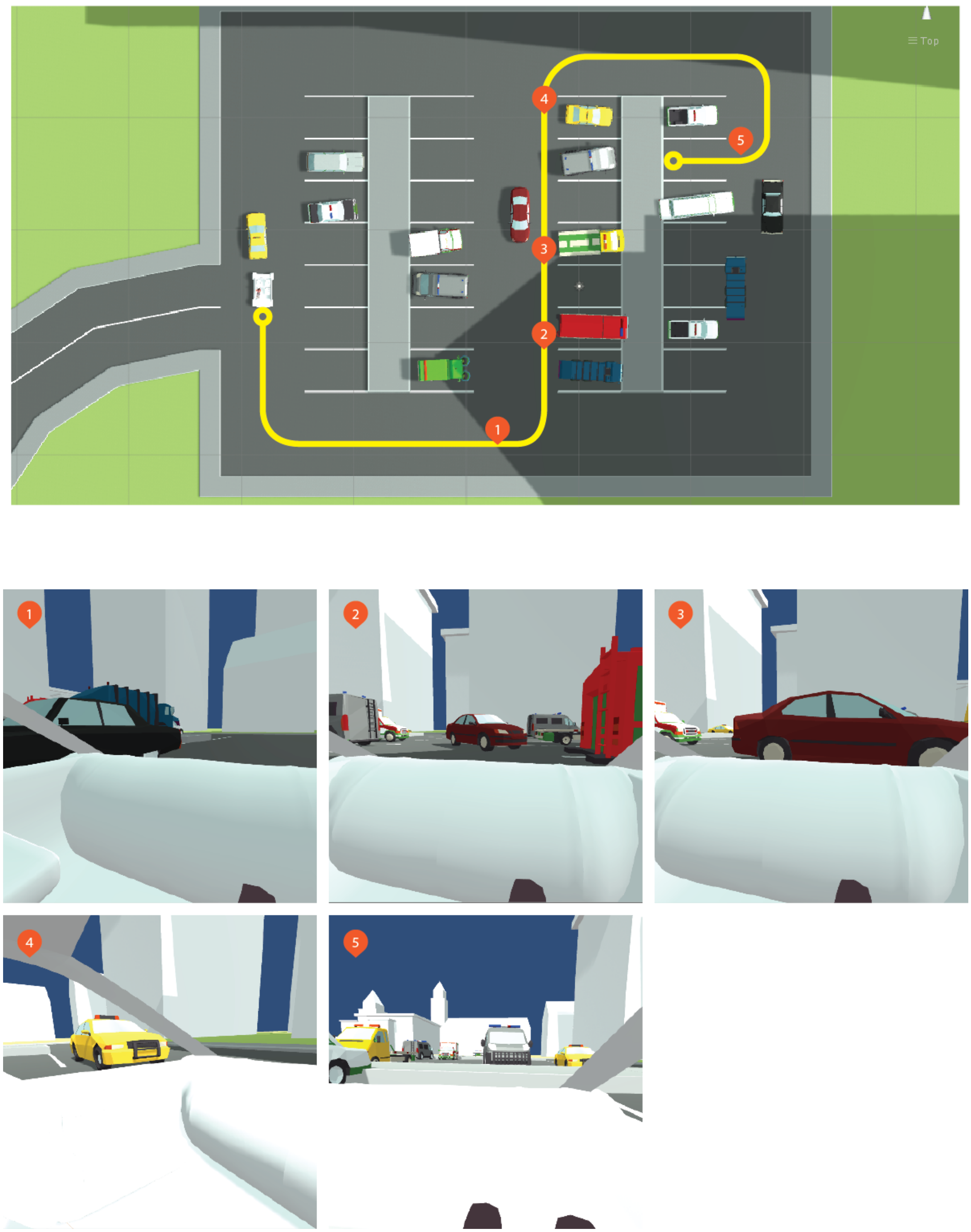
Car Behavior

	Too far				Too close
Distance with front vehicle					
	Too slow				Too fast
Speed					
	Too defensive				Too aggressive
Aggressiveness					

A.5 Scenario Overview




1
2
3
4
1
2
3
4
5


Top
1
2
3
4
5

APPENDIX B. DATA ANALYSIS

B.1 Gesture Coding

	Pattern		Body Part				Interface					Detail			Complexity	
	Saltatory	Incremental	Head	Torso	Upper limb	Lower limb	In-air	Dashboard	Handle	Foot Mat	Seat	Low	Moderate	High	Simple	Compound
a-1	5			2.5		2.5				2.5	2.5	5				5
a-2	3				3		3						3		3	
a-3	2					2				2			2		2	
a-4	1				1			1					1		1	
b-1		5			5						5	5			5	
b-2		2				2				2			2		2	
b-3		2			2		2						2		2	
b-4		1			1		1						1		1	
b-5		1			1				1				1		1	
c-1		7			7		7						7		7	
c-2		3				3				3			3		3	
c-3		1			1		1							1	1	
d-1		5		5							5		5		5	
d-2		4			4		4						4		4	
d-3	2				2		2						2		2	
e-1	7				7		7							7	7	
e-2	3				3		3						3		3	
e-3	1		1				1						1		1	
	24	31	1	7.5	37	9.5	31	1	1	9.5	12.5	10	37	8	50	5

B.2 Agreement Score Calculation

$$A_{stop} = \left(\frac{|5|}{|11|}\right)^2 + \left(\frac{|3|}{|11|}\right)^2 + \left(\frac{|2|}{|11|}\right)^2 + \left(\frac{|1|}{|11|}\right)^2 = 0.32$$

$$A_{slow\text{-}down} = \left(\frac{|5|}{|11|}\right)^2 + \left(\frac{|2|}{|11|}\right)^2 + \left(\frac{|2|}{|11|}\right)^2 + \left(\frac{|1|}{|11|}\right)^2 + \left(\frac{|1|}{|11|}\right)^2 = 0.29$$

$$A_{speed\text{-}up} = \left(\frac{|7|}{|11|}\right)^2 + \left(\frac{|3|}{|11|}\right)^2 + \left(\frac{|1|}{|11|}\right)^2 = 0.49$$

$$A_{direction} = \left(\frac{|5|}{|11|}\right)^2 + \left(\frac{|4|}{|11|}\right)^2 + \left(\frac{|2|}{|11|}\right)^2 = 0.37$$

$$A_{referring} = \left(\frac{|7|}{|11|}\right)^2 + \left(\frac{|3|}{|11|}\right)^2 + \left(\frac{|1|}{|11|}\right)^2 = 0.49$$

REFERENCES

Alexander, A. L., Brunyé, T., Sidman, J., & Weil, S. A. (2005). From Gaming to Training: A Review of Studies on Fidelity, Immersion, Presence, and Buy-in and Their Effects on Transfer in PC-Based Simulations and Games. *Annals of Thoracic Surgery*, *80*(1), 357–358. https://doi.org/10.1016/j.athoracsur.2004.02.012

Alvarez, I., Rumbel, L., & Adams, R. (2015). Skyline- a Rapid Prototyping Driving Simulator for User Experience. *Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications - AutomotiveUI '15*, 101–108. https://doi.org/10.1145/2799250.2799290

Bellem, H., Klüver, M., Schrauf, M., Schöner, H. P., Hecht, H., & Krems, J. F. (2017). Can We Study Autonomous Driving Comfort in Moving-Base Driving Simulators? A Validation Study. *Human Factors*, *59*(3), 442–456. https://doi.org/10.1177/0018720816682647

Bellem, H., Schönenberg, T., Krems, J. F., & Schrauf, M. (2016). Objective metrics of comfort: Developing a driving style for highly automated vehicles. *Transportation Research Part F: Traffic Psychology and Behaviour*, *41*, 45–54. https://doi.org/10.1016/j.trf.2016.05.005

Bodiroža, S., Stern, H. I., & Edan, Y. (2012). Dynamic Gesture Vocabulary Design for Intuitive Human-robot Dialog. In *Proceedings of the Seventh Annual ACM/IEEE International Conference on Human-Robot Interaction* (pp. 111–112). New York, NY, USA: ACM. https://doi.org/10.1145/2157689.2157710

Brown, B., & Laurier, E. (2017). The Trouble with Autopilots: Assisted and autonomous driving on the social road Barry. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 416–429. https://doi.org/10.1145/3025453.3025462

Craighead, J., Murphy, R., Burke, J., & Goldiez, B. (2007). A survey of commercial & open source unmanned vehicle simulators. *Proceedings - IEEE International Conference on Robotics and Automation*, (April), 852–857. https://doi.org/10.1109/ROBOT.2007.363092

Elander, J., West, R., & French, D. (1993). Behavioral correlates of individual differences in road-traffic crash risk: An examination of methods and findings. *Psychological Bulletin*. US: American Psychological Association. https://doi.org/10.1037/0033-2909.113.2.279

Elbanhawi, M., Simic, M., & Jazar, R. (2015). In the Passenger Seat: Investigating Ride Comfort Measures in Autonomous Cars. *IEEE Intelligent Transportation Systems Magazine*, *7*(3), 4–17. https://doi.org/10.1109/MITS.2015.2405571

England, D. (2011). Whole Body Interaction: An Introduction BT - Whole Body Interaction. In D. England (Ed.) (pp. 1–5). London: Springer London. https://doi.org/10.1007/978-0-85729-433-3_1

Fagnant, D., & Kockelman, K. M. (2014). THE TRAVEL AND ENVIRONMENTAL IMPLICATIONS OF SHARED AUTONOMOUS VEHICLES, USING AGENT-BASED

MODEL SCENARIOS. *Transportation Research Part C: Emerging Technologies*, *40*, 1–13. https://doi.org/10.4028/www.scientific.net/amr.361-363.499

Fogtmann, M. H., Fritsch, J., & Kortbek, K. J. (2008). Kinesthetic Interaction: Revealing the Bodily Potential in Interaction Design. In *Proceedings of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat* (pp. 89–96). New York, NY, USA: ACM. https://doi.org/10.1145/1517744.1517770

Gold, C., Körber, M., Hohenberger, C., Lechner, D., & Bengler, K. (2015). Trust in Automation – Before and After the Experience of Take-over Scenarios in a Highly Automated Vehicle. *Procedia Manufacturing*, *3*(Ahfe), 3025–3032. https://doi.org/10.1016/j.promfg.2015.07.847

Hammar, J., & Karlsson, A. (2015). The Design of a Multi-touch Gestural System for Semi-autonomous Driving, 57. https://doi.org/http://studentarbeten.chalmers.se/publication/224233-the-design-of-a-multi-touch-gestural-system-for-semi-autonomous-driving

Jamson, S. (2006). Would those who need ISA, use it? Investigating the relationship between drivers' speed choice and their use of a voluntary ISA system. *Transportation Research Part F: Traffic Psychology and Behaviour*, *9*(3), 195–206. https://doi.org/10.1016/j.trf.2005.11.002

Karjanto, J., Delbressine, F., Terken, J., Yusof, N. M., Rauterberg, M., & Hassan, M. Z. (2017). The Exploration of Autonomous Vehicle Driving Styles, 245–252. https://doi.org/10.1145/3003715.3005455

Karjanto, J., Md. Yusof, N., Terken, J., Delbressine, F., Hassan, M. Z., & Rauterberg, M. (2016). Simulating autonomous driving styles: Accelerations for three road profiles. *MATEC Web of Conferences*, *90*, 01005. https://doi.org/10.1051/matecconf/20179001005

Li, S., Li, K., Rajamani, R., & Wang, J. (2011). Model predictive multi-objective vehicular adaptive cruise control. *IEEE Transactions on Control Systems Technology*, *19*(3), 556–566. https://doi.org/10.1109/TCST.2010.2049203

Miyajima, C., Nishiwaki, Y., Ozawa, K., Wakita, T., Itou, K., Takeda, K., & Itakura, F. (2007). Driver Modeling Based on Driving Behavior and Its Evaluation in Driver Identification. *Proceedings of the IEEE*, *95*(2), 427–437. https://doi.org/10.1109/JPROC.2006.888405

Morris, M., Wobbrock, J., & Wilson, A. (2010). Understanding users' preferences for surface gestures. *Proceedings of Graphics Interface*, 261–268. https://doi.org/10.1016/j.actamat.2009.07.058

Ng, A., Brewster, S. A., Beruscha, F., & Krautter, W. (2017). An Evaluation of Input Controls for In-Car Interactions. *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems - CHI '17*, 2845–2852. https://doi.org/10.1145/3025453.3025736

Payre, W., Cestac, J., & Delhomme, P. (2016). Fully Automated Driving: Impact of Trust and Practice on Manual Control Recovery. *Human Factors*, *58*(2), 229–241. https://doi.org/10.1177/0018720815612319

Ruiz, J. (2011). Motiongestures-Chi2011.Pdf.

Ruiz, J., Li, Y., & Lank, E. (2011). User-defined motion gestures for mobile interaction, 197. https://doi.org/10.1145/1978942.1978971

SAE International. (2015). Taxonomy and Definitions for Terms Related to Driving Automation Systems for On-Road Motor Vehicles.

Siebert, F. W., Oehl, M., Höger, R., & Pfister, H.-R. (2013). Discomfort in Automated Driving -- The Disco-Scale. In C. Stephanidis (Ed.), *HCI International 2013 - Posters' Extended Abstracts* (pp. 337–341). Berlin, Heidelberg: Springer Berlin Heidelberg.

Slob, J. J. (2008). State-of-the-Art Driving Simulators, a Literature Survey. *DCT Report*, (DCT 2008.107), 19. https://doi.org/10.1117/12.776394

Sportillo, D., Paljic, A., Ojeda, L., Fuchs, P., & Roussarie, V. (2018). Light Virtual Reality Systems for the Training of Conditionally Automated Vehicle Drivers. Retrieved from https://arxiv.org/pdf/1803.04968.pdf

Stern, H. I., Wachs, J. P., & Edan, Y. (2006). Human Factors for Design of Hand Gesture Human - Machine Interaction. In *2006 IEEE International Conference on Systems, Man and Cybernetics* (Vol. 5, pp. 4052–4056). https://doi.org/10.1109/ICSMC.2006.384767

Taheri, S. M., Matsushita, K., & Sasaki, M. (2017). Development of a Driving Simulator with Analyzing Driver's Characteristics Based on a Virtual Reality Head Mounted Display. *Journal of Transportation Technologies*, *07*(03), 351–366. https://doi.org/10.4236/jtts.2017.73023

Taubman-ben-ari, O., Mikulincer, M., & Gillath, O. (2004). The multidimensional driving style inventory — scale construct and validation, *36*, 323–332. https://doi.org/10.1016/S0001-4575(03)00010-1

Tomita, A., Harada, E. T., & Ando, S. (2017). On-time Measurement of Subjective Anxiety of a Passenger in an Autonomous Vehicle：Gradually Changing Sounds Decreases Anxiety of Passenger, *10275*, 209–219. https://doi.org/10.1007/978-3-319-58472-0

Tscharn, R., Latoschik, M. E., Löffler, D., & Hurtienne, J. (2017). "Stop over there": natural gesture and speech interaction for non-critical spontaneous intervention in autonomous driving. *Proceedings of the 19th ACM International Conference on Multimodal Interaction - ICMI 2017*, (November), 91–100. https://doi.org/10.1145/3136755.3136787

Tudor, S., Carey, S., & Dubey, R. (2015). Development and evaluation of a dynamic virtual reality driving simulator. *8th ACM International Conference on PErvasive Technologies Related to Assistive Environments, PETRA 2015 - Proceedings*. https://doi.org/10.1145/2769493.2769593

Underwood, G., Crundall, D., & Chapman, P. (2011). Driving simulator validation with hazard perception. *Transportation Research Part F: Traffic Psychology and Behaviour*, *14*(6), 435–446. https://doi.org/10.1016/j.trf.2011.04.008

Vatavu, R.-D., & Wobbrock, J. O. (2015). Formalizing Agreement Analysis for Elicitation Studies. *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15*, 1325–1334. https://doi.org/10.1145/2702123.2702223

Wachenfeld, W., Winner, H., Gerdes, J. C., Lenz, B., Maurer, M., Beiker, S., … Winkle, T. (2016). Use Cases for Autonomous Driving BT - Autonomous Driving: Technical, Legal and Social Aspects. In M. Maurer, J. C. Gerdes, B. Lenz, & H. Winner (Eds.) (pp. 9–37). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-48847-8_2

Walch, M., Frommel, J., Rogers, K., Schüssel, F., Hock, P., Dobbelstein, D., & Weber, M. (2017). Evaluating VR Driving Simulation from a Player Experience Perspective. *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '17*, 2982–2989. https://doi.org/10.1145/3027063.3053202

Wei, J., Snider, J. M., Kim, J., Dolan, J. M., Rajkumar, R., & Litkouhi, B. (n.d.). Towards a Viable Autonomous Driving Research Platform.

Wobbrock, J. O., Aung, H. H., Rothrock, B., & Myers, B. A. (2005). Maximizing the guessability of symbolic input, (January), 1869. https://doi.org/10.1145/1056808.1057043

Wobbrock, J. O., Morris, M. R., & Wilson, A. D. (2009). User-defined gestures for surface computing. *Proceedings of the 27th International Conference on Human Factors in Computing Systems - CHI 09*, 1083. https://doi.org/10.1145/1518701.1518866

Wu, H., Wang, J., & Zhang, X. (Luke). (2016). User-centered gesture development in TV viewing environment. *Multimedia Tools and Applications*, *75*(2), 733–760. https://doi.org/10.1007/s11042-014-2323-5